Space Weather Monitoring Improves International Space Station Extravehicular Activity Safety and Operations

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The orbit of the International Space Station (ISS) causes the vehicle to pass through electrically conducting layers of the Earth's ionosphere. This environment, in combination with the 160-volt solar array power system on the ISS, facilitates an accumulation of varying electrical charge on the vehicle. The charge corresponds to an intrinsic electrical potential, posing a possibly catastrophic hazard to crew safety during extravehicular activity (EVA).

Recently, NASA—with support from Boeing (Houston, Texas)—has been engaged in studies of solar state and its effect on ionospheric conditions with the goal of providing operational constraint relief during EVA on the ISS.

Plasma contactor units (PCUs) operate during EVA to control the charging hazard. The corresponding electrical potential must be maintained to less than 40 volts between the ISS structure and the external ionospheric plasma. PCUs expel an artificially generated plasma, providing low resistance grounding path to bleed off any excess charge from the ISS. This achieves the specified hazard control.

There are two PCUs providing only two-fold redundancy and a third control is required according to NASA safety requirements for controlling possibly catastrophic hazards. This third control—invoked in the event that one PCU fails—is a carefully planned procedure consisting of an emergency shutdown of all eight ISS solar arrays to eliminate the immediate electrical hazard followed by a re-enabling of two arrays, thus permitting the EVA to go forward but with reduced power capability.

The careful planning of the emergency solar array shutdown is contingent on variables associated with the state of the ionopsheric plasma environment determined largely by preconditioning physical effects from the sun. The sun provides a highly variable ultraviolet flux that determines the plasma density (N_e) and the temperature of its electrons (T_e). The variability (N_e, T_e) plasma state is referred to as a space weather effect. Space weather along with the vehicle attitude directly determine the amount of electrical charge collected by the ISS. NASA's PCU failure contingency is planned according to the severity of worst-case attitude and plasma state scenarios determined though examination of historic records of ionosphere plasma conditions.

However, the worst-case conditions in the historic space weather climatology record place constraints on operations the can be relieved if real-time conditions can be monitored. As part of the ongoing process improvement activity, NASA, with the support of Boeing, is engaged in efforts to achieve this real-time space weather monitoring and, to the extent possible, relieve the constraints on mission power imposed by the existing PCU failure contingency.

There are resources available for monitoring and evaluating the plasma environment. NASA has developed a Floating Potential Measurement Unit (FPMU), which is a suite of instrumentation that provides diagnostic information originally deployed to validate the Plasma Interaction Model developed by Boeing for the purpose of understanding and controlling the charging properties of the ISS.

These tools are used for the contingency planning. Prior to any EVA, N_e, T_e, and floating potential (FP) are measured by the FPMU. These data are compared to the historic data set to determine whether the ionosphere is in a pre-established standard condition deemed sub-nominal (–2 Sigma), nominal (+/–1 Sigma), or active state (+2 Sigma). Figure 1 is a plot of N_e, T_e, and FP calculations given from the model for a pre-established environmental standard conditions.

The hazard condition usually occurs when the ISS emerges from eclipse. The data in figure 1 show that a –2 Sigma environment typically exhibits N_e below 1×10^{11} m^{-3} (per cubic meter). The nominal, +/–1 Sigma environment has a density about 5×10^{11} m^{-3} and the active environment; the +2 Sigma environment exhibits an enhanced density exceeding 10×10^{11} m^{-3}.

The calculated FP exemplifies the effect of plasma density on the electrical charging state of the vehicle. In the –2 Sigma state, FP ranges from about –8 to –25 volts. In the nominal case, FP ranges from –35 to –40 volts; in the active case, the FP is more negative than –40 volts. The active case violates operational hazard control constraints whereas the nominal and sub-nominal cases are within safe limits.

The active ionospheric case must be protected against but is not uniformly present. Based on the historical space weather climatology, tables are prepared that specify the number of solar arrays that need to be pointed to wake during a PCU failure. This task is performed for each EVA.

Without real-time monitoring, the plan for PCU failure would continue the EVA with only two arrays active, which would impose severe restrictions on operational capability resulting from the lost electrical power and often leads to required termination of the EVA.

However, figure 2 illustrates the actual measured state (N_e, T_e, and FP) of the ionosphere for comparison with the model predictions based on historical climatology in figure 1. The actual floating potential experienced by the vehicle was much less severe than that predicted according to the worst-case planning. This is a result of lower-density plasma prevailing at times when worst-case planning predicted severe charging.

Figure 3 is a product produced to support EVA according to the improved process. This table shows that the largest FP at critical positions on the ISS structure for the range of Sigma state conditions.

Because it was determined that the environment in this example is in a sub-nominal state, only two of the eight arrays needed to be taken out of service. Previously it would have been necessary to shut down six arrays.

Work is continuing to streamline processes and to exploit other space weather forecasting metrics. Predicting the state of the ionosphere is challenging, owing to scientific uncertainty concerning the physics controlling solar activity

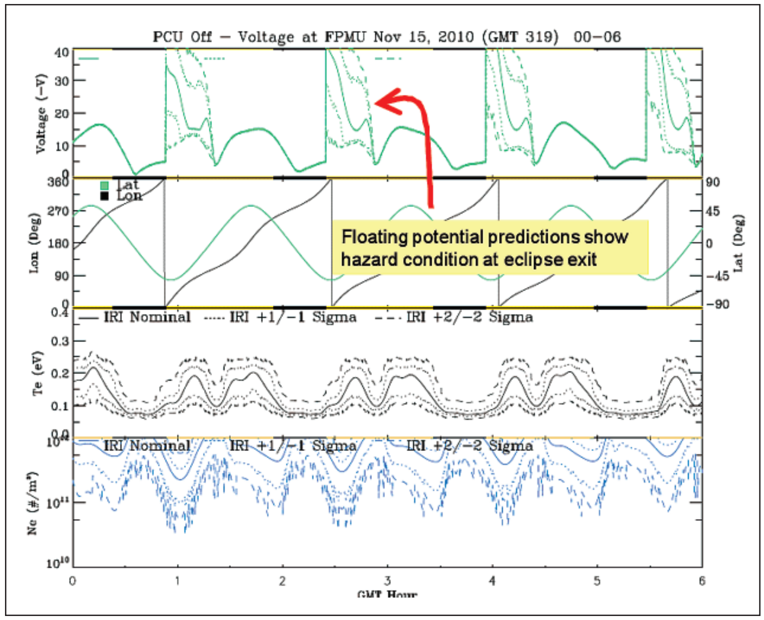

Fig. 1. *Plasma Interaction Model floating potential predictions for differing (including worst-case planning).*

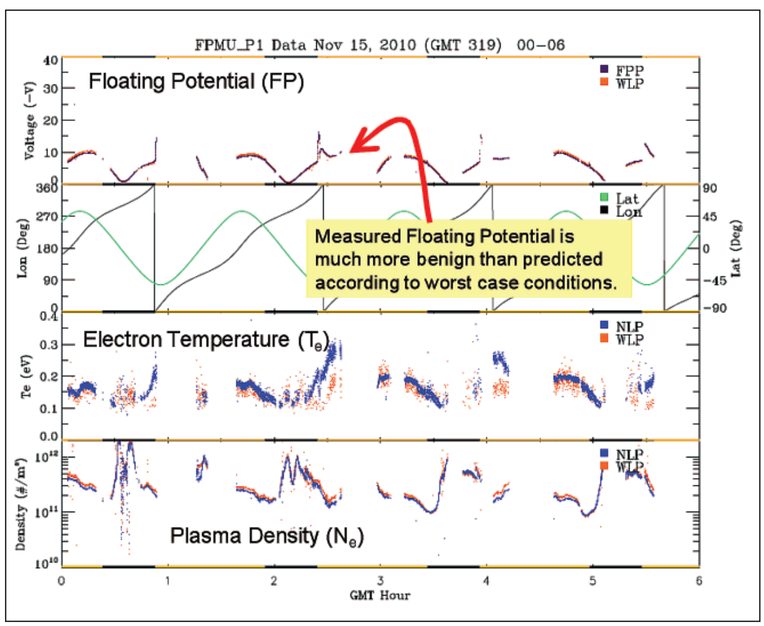

Fig. 2. *Floating Potential Measurement Unit observations show that the actual state of the ionosphere was much less severe than that predicted by worst-case conditions.*

GMT Day	Shunt	Config	Attitude	+2 Sigma Port Truss Tip	+2 Sigma Stbd Truss Tip	+2 Sigma Port SARJ	+2 Sigma Stbd SARJ	+2 Sigma center	0 Sigma Port Truss Tip	0 Sigma Stbd Truss Tip	0 Sigma Port SARJ	0 Sigma Stbd SARJ	0 Sigma center
2010_319	All	Complete	XVV	-36.91	-32.27	-28.14	-24.60	-18.35	-36.99	-32.41	-28.21	-24.75	-18.42
2010_319	S4,P4,P6	Complete	XVV	-39.00	-32.31	-30.22	-24.65	-20.44	-37.86	-32.40	-29.12	-24.74	-19.42
2010_319	S4,P4,S6	Complete	XVV	-37.98	-32.31	-29.20	-24.65	-19.43	-37.40	-32.36	-28.63	-24.70	-18.87
2010_319	P4,P6,S6	Complete	XVV	-38.85	-32.29	-30.08	-24.63	-20.32	-37.76	-32.41	-29.02	-24.74	-19.32
2010_319	S4,P6,S6	Complete	XVV	-38.10	-32.30	-29.33	-24.64	-19.54	-37.48	-32.37	-28.70	-24.70	-18.91
2010_319	S4,P4	Complete	XVV	-40.63	-32.29	-32.96	-24.62	-28.77	-38.46	-32.39	-29.72	-24.73	-25.16
2010_319	P4,P6	Complete	XVV	-47.39	-32.28	-38.69	-27.50	-32.43	-38.99	-32.39	-33.13	-24.73	-28.64
2010_319	S4,P6	Complete	XVV	-41.59	-32.30	-33.90	-25.10	-29.31	-38.57	-32.41	-29.98	-24.75	-25.67
2010_319	P4,S6	Complete	XVV	-40.29	-32.29	-32.15	-24.62	-28.29	-38.38	-32.39	-29.64	-24.73	-24.64
2010_319	S4,S6	Complete	XVV	-39.38	-32.25	-30.66	-24.59	-25.99	-37.90	-32.40	-29.14	-24.74	-22.37
2010_319	P6,S6	Complete	XVV	-40.62	-32.28	-33.00	-24.62	-28.78	-38.50	-32.35	-29.76	-24.69	-25.12
2010_319	P4	Complete	XVV	-55.68	-36.71	-48.76	-39.73	-43.99	-48.59	-32.36	-44.06	-35.14	-39.71
2010_319	S4	Complete	XVV	-50.81	-34.91	-45.53	-37.78	-41.96	-45.68	-32.41	-41.22	-33.19	-37.56
2010_319	P6	Complete	XVV	-56.80	-37.14	-49.51	-40.14	-44.49	-49.16	-32.44	-44.66	-35.57	-40.21
2010_319	S6	Complete	XVV	-49.93	-34.51	-44.89	-37.35	-41.47	-45.01	-32.41	-40.62	-32.77	-37.13
2010_319	None	Complete	XVV	-62.71	-45.72	-56.99	-48.69	-52.89	-56.69	-40.65	-52.23	-43.77	-48.25

GMT Day	Shunt	-1 Sigma Port Truss Tip	-1 Sigma Stbd Truss Tip	-1 Sigma Port SARJ	-1 Sigma Stbd SARJ	-1 Sigma center	-2 Sigma Port Truss Tip	-2 Sigma Stbd Truss Tip	-2 Sigma Port SARJ	-2 Sigma Stbd SARJ	-2 Sigma cen
2010_319	All	-37.04	-32.39	-28.27	-24.72	-18.48	-37.05	-32.42	-28.28	-24.76	-18.
2010_319	S4,P4,P6	-37.60	-32.39	-28.82	-24.72	-19.05	-37.49	-32.39	-28.72	-24.73	-18.
2010_319	S4,P4,S6	-37.26	-32.40	-28.49	-24.74	-18.72	-37.28	-32.45	-28.51	-24.78	-18.
2010_319	P4,P6,S6	-37.49	-32.38	-28.72	-24.72	-18.95	-37.45	-32.40	-28.68	-24.74	-18.
2010_319	S4,P6,S6	-37.34	-32.38	-28.57	-24.72	-18.78	-37.32	-32.40	-28.55	-24.74	-18.
2010_319	S4,P4	-37.85	-32.41	-29.08	-24.75	-21.26	-37.71	-32.43	-28.94	-24.77	-19.
2010_319	P4,P6	-38.12	-32.39	-29.35	-24.73	-24.14	-37.94	-32.45	-29.17	-24.79	-19.
2010_319	S4,P6	-37.90	-32.40	-29.12	-24.73	-21.74	-37.76	-32.44	-28.99	-24.78	-19.
2010_319	P4,S6	-37.78	-32.37	-29.01	-24.71	-20.69	-37.65	-32.46	-28.88	-24.80	-19.
2010_319	S4,S6	-37.59	-32.37	-28.82	-24.70	-19.05	-37.47	-32.39	-28.70	-24.73	-18.
2010_319	P6,S6	-37.81	-32.43	-29.04	-24.77	-21.22	-37.72	-32.42	-28.95	-24.76	-19.
2010_319	P4	-42.05	-32.41	-38.16	-29.97	-34.79	-38.16	-32.43	-29.39	-24.77	-22.
2010_319	S4	-39.68	-32.37	-36.03	-28.00	-32.72	-37.97	-32.40	-29.19	-24.74	-20.
2010_319	P6	-42.57	-32.37	-38.60	-30.41	-35.27	-38.20	-32.46	-29.46	-24.80	-23.
2010_319	S6	-39.15	-32.41	-35.55	-27.59	-32.20	-37.92	-32.43	-29.15	-24.77	-20.
2010_319	None	-49.95	-34.98	-46.32	-38.15	-42.92	-38.55	-32.41	-33.17	-24.75	-29.

Fig. 3. *Real-time monitoring permits identification of benign International Space Station charging environmental conditions.*

and the ionosphere's response to it. For example, in recent years, the activity of the sun has been anomalously weak and this was not predicted by the scientific community.

The FPMU instrumentation was originally commissioned to validate Boeing modeling effort. However, its value to the ISS as a source of real-time data for the purpose of supporting EVA safety has become apparent. FPMU measurements are now a part of formal operational planning and its ground support equipment are being upgraded for long-term program use.

In summary, NASA, with Boeing's support, has been working toward real-time monitoring of the ionospheric environment associated with space weather influences for the purpose of relieving constraints on power availability in the event of PCU failure during an EVA. These efforts have yielded clear improvements that permit nearly normal operations during the majority of any EVA contingency involving PCU failure. The increased power availability has the effect of increasing productivity of the operations workforce at minimal cost without impacting safety.